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Airborne Lidar Simulator for the Lidar Surface Topography (LIST) Mission

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Outline

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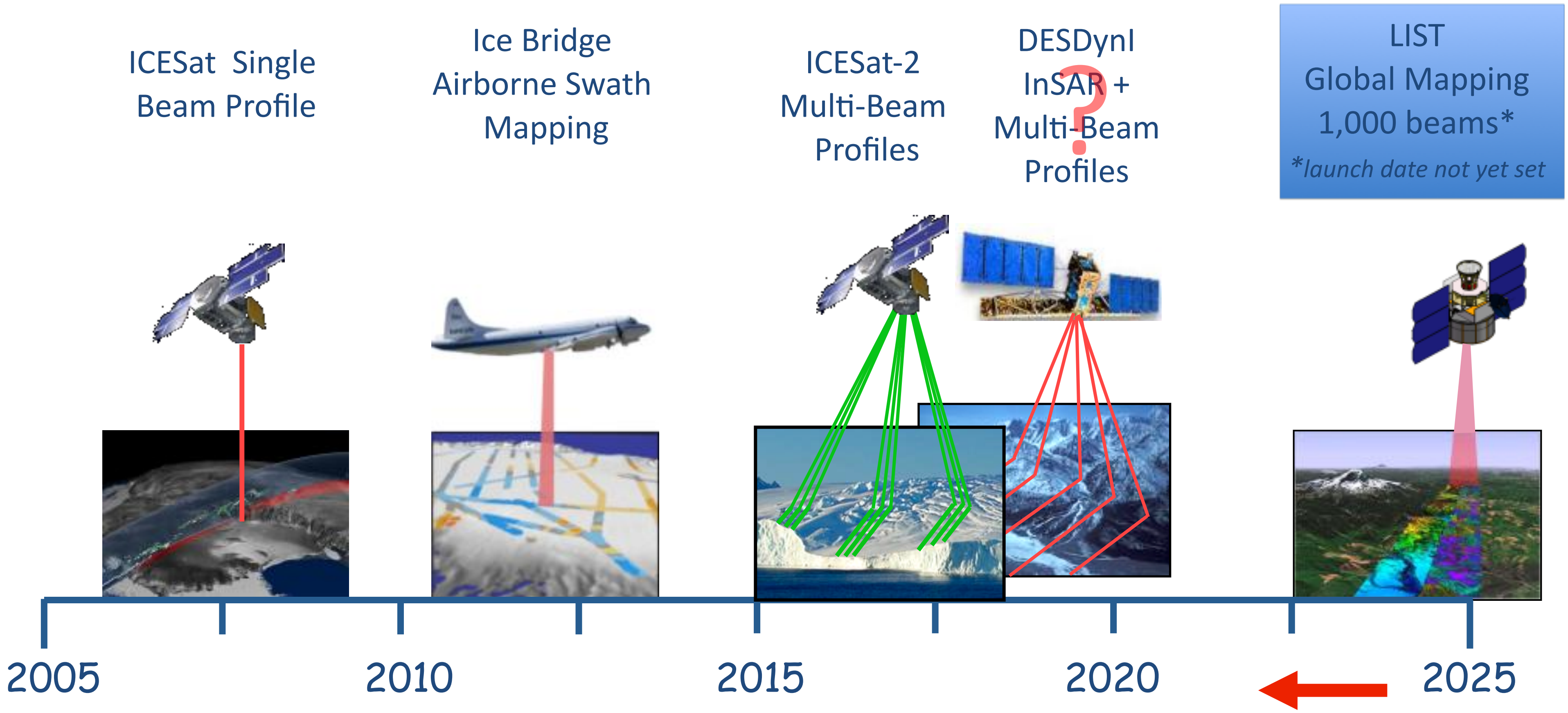
- Introduction
- LIST Science Objectives & Requirements
- Lidar Measurement Approach & Performance Analysis
- Airborne Instrument Development
- Summary

LIDAR SURFACE TOPOGRAPHY (LIST) SCIENCE OBJECTIVES & REQUIREMENTS

LIST Mission Context

Evolution of NASA Earth Science Laser Altimeter Missions

NRC Earth Science Decadal Survey Missions



Cancellation of DESDynI Lidar => LIST is next lidar altimetry mission after ICESat-2

LIST Science Objectives

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LIST will provide high-resolution elevation images of the Earth's solid surface & its overlying covers of vegetation, water, snow, ice and manmade structures.

Provides data fundamental to understanding, modeling and predicting interactions between the Solid Earth, hydrosphere, biosphere, cryosphere and atmosphere.

Solid Earth
- landscape evolution
- climate/tectonics/ erosion interactions
- earthquake, volcano, landslide and coastal hazards

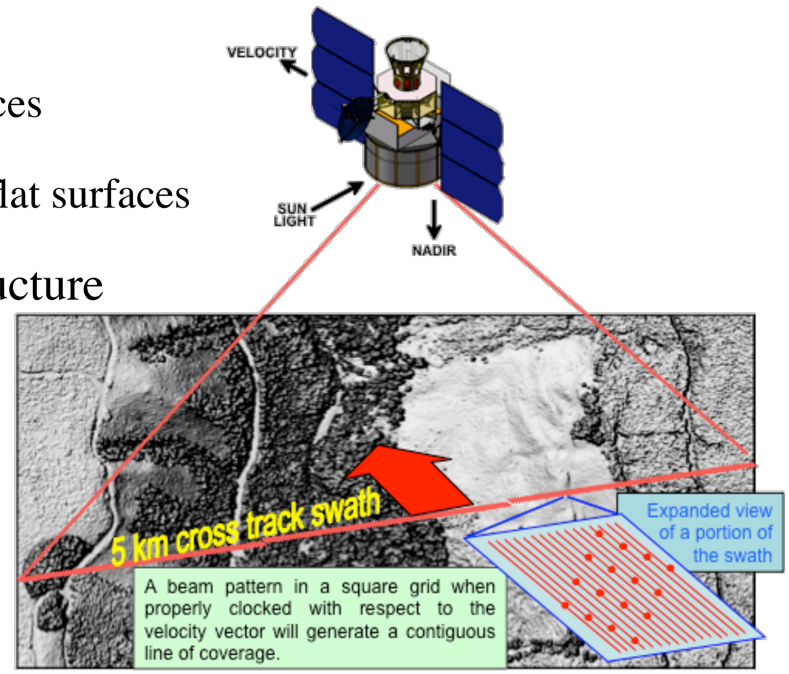
Vegetation Structure
- carbon storage
- disturbance & response
- habitat and biodiversity
- wild-fire fuel loads
- slope stabilization

Cryosphere
- ice sheet, ice cap, glacier elevation change
- ice flow and dynamics
- sea ice cover & thickness

Water Cycle
- water storage
- snow depth
- river discharge

LIST Measurement Requirements

- Acquire elevation images of land topography, including where covered by vegetation, and inland water bodies, ice sheets, glaciers and snow cover
  - 5 m spatial resolution (i.e., pixel size)
  - ≤ 10 cm vertical precision per 5 m pixel for flat surfaces
  - ≤ 20 cm absolute vertical accuracy per 5 m pixel for flat surfaces
- Acquire images of vegetation height and vertical structure
  - 1 m vertical resolution per 25 m x 25 m area
- Complete one-time global mapping in 3 years
  - Implies a 5 km or wider swath to build up coverage during clear sky conditions
- Repeat mapping for change monitoring in selected areas
  - Monthly for water storage and natural hazard topographic change
  - Seasonally for ice sheet, sea ice and vegetation structure change



LIST - Challenges for a Space Lidar

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- Complete mapping of the entire Earth in 3 years with 5-m spatial resolution

  –> 5 km Swath with 1000 parallel profiling lines (or channels)
- Detecting ground echoes through tree canopies (2% opening) under clear sky conditions (~70% one way transmission)
- Alignment of 1000 transmitters and receiver optics
- 1000 channel data acquisition, processing, and storage
- Resource Goals: < 10 KW peak electrical power and <700 kg mass

Need approach with high "measurement efficiency:"

- ✓ **Highest laser 'wall-plug efficiency'**
- ✓ **Measurement wavelength with high surface reflectance, low atmosphere loss and good receiver QE**
- ✓ **Highest receiver sensitivity – single photon detection**
- ✓ **Wide receiver dynamic range – linear photon detection**
- ✓ **Practical receiver signal processing & hardware implementation**

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LIDAR MEASUREMENT APPROACH & PERFORMANCE ANALYSIS

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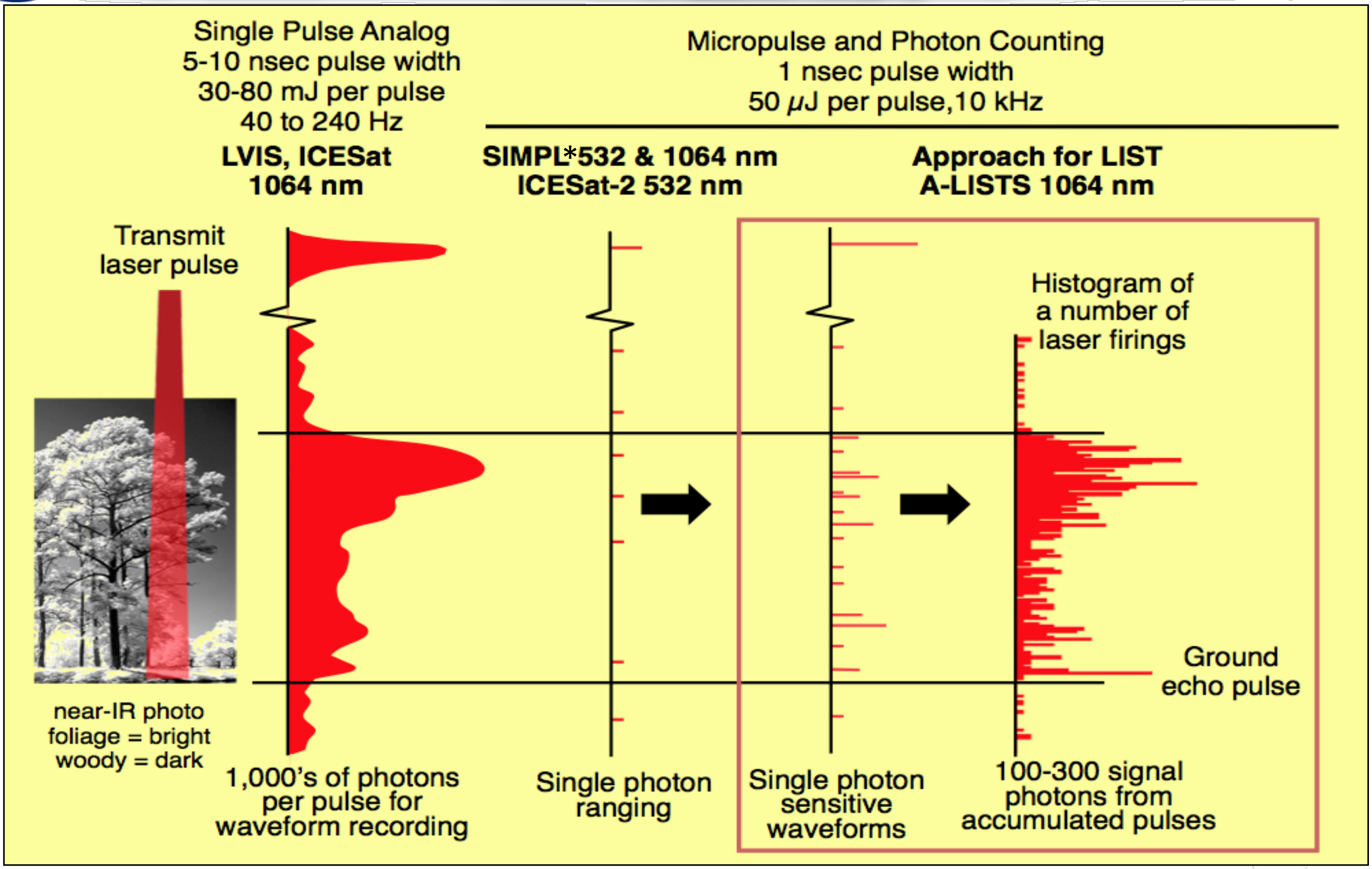
Lidar Measurement Approaches
- Single Photon Detection and Averaging



** - SIMPL – Slope Imaging Multi-polarization Photon-counting Lidar (D. Harding, PI, NASA /GSFC)*

LIST with 1030 nm PMT Detection - Space - NIR PMT Single Photon Sensitivity

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Approach:

Photon sensitive detection
PMT -> analog digitizer
Multiple laser pulse histogramming
NIR-PMT detector: 10% QE

Laser Illumination:

Laser fire rate along track: 10 KHz
Laser firings/pixel: 7
Laser energy/pulse: 50 uJ
Ave Power/track: 0.5 W
Ave Laser E. Power/track: 5 W
Meets LIST efficiency goals

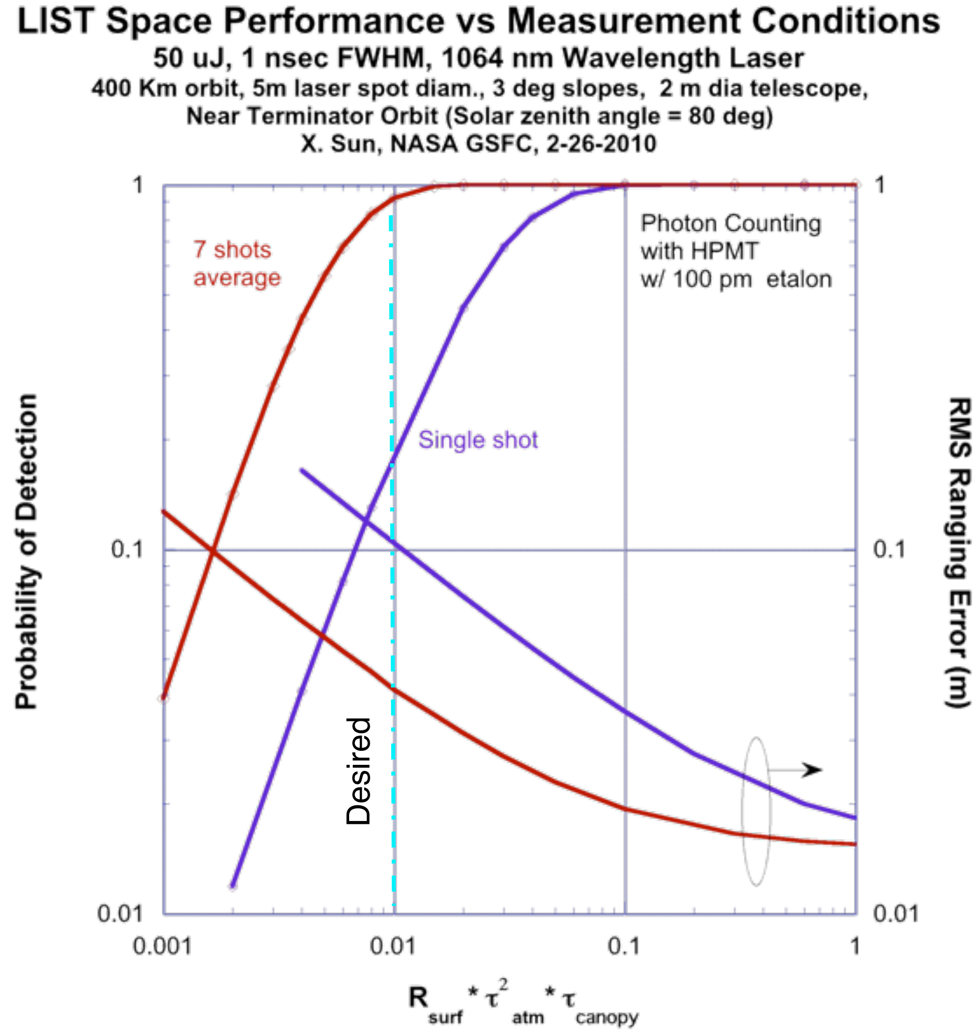
Detection Probability:

>90% after averaging received signal over 7 laser shots

Range jitter:

Vertical offset - laser pulse range spread
Floor set - digitizer rate (1.5 GHz)

Model From: Harding IIP-04



• *NIR PMT detection improves receiver sensitivity by x7*

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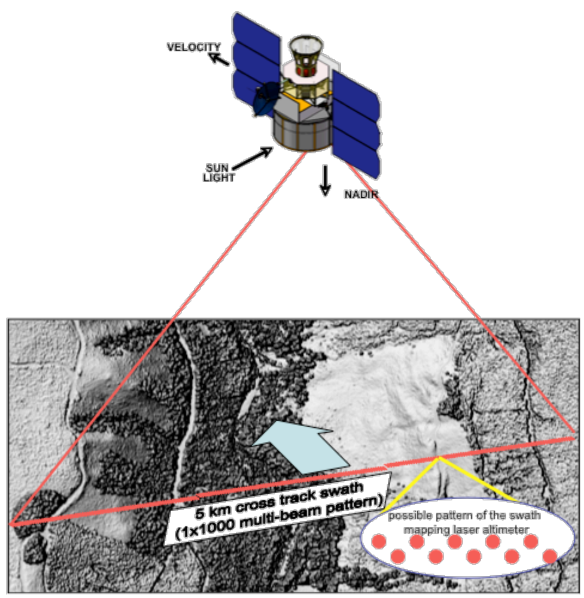
Space and Airborne Measurement Comparison

Both use micropulse lidar with waveform capturing and analysis detection scheme

Parameters	Spaceborne Instrument	Airborne Instrument
Spatial Resolution	5 meter	5 meter
Altitude	400 km	10 km
Swath Width	5 km	80 m
Laser Energy (PRF @ 10 kHz)	50 µJ per beam for 1000 beam	6 µJ per beam for 16 beam (IPD) 100 µJ per beam for 16 beam (I2E)
Detector (> 1 GHz bandwidth/pixel)	1000 pixels	16 pixels
Platform Speed	7000 m/sec	200 m/sec
Number of samples per 5-m footprint	7	250

First flight – Sept 2011



Lear 25 Aircraft Data	
Wingspan	35 ft 8 in (10.84 m)
Length	47 ft 7 in (13.18 m)
Height	12 ft 3 in (3.73 m)
Powerplants	General Electric CJ-610-6, axial-flow turbojet engines

Microchip Yb:YAG Oscillator

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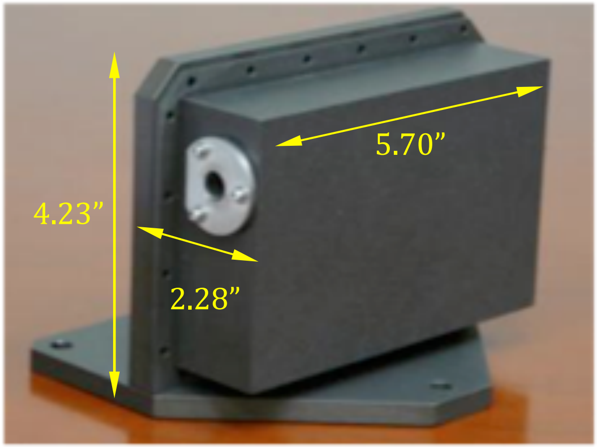
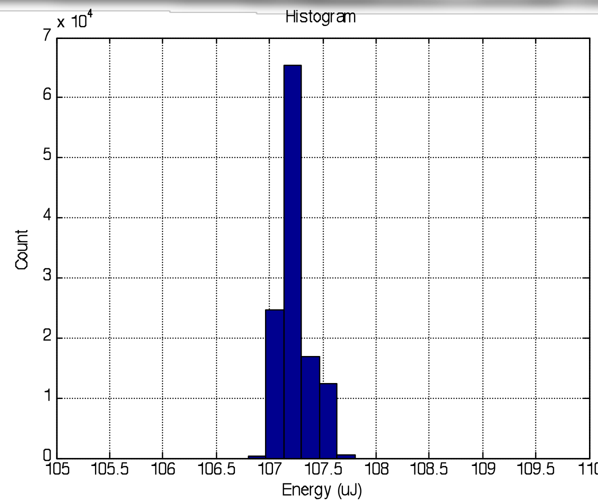
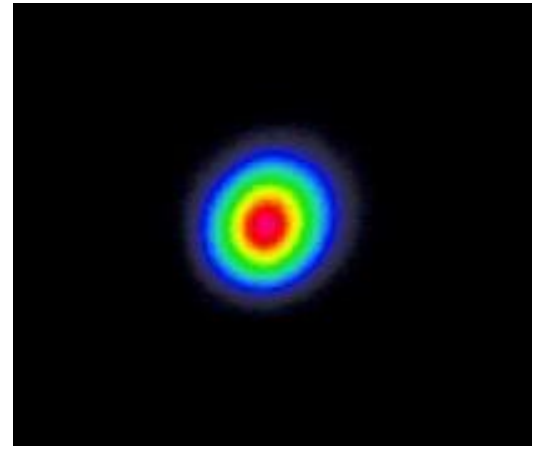




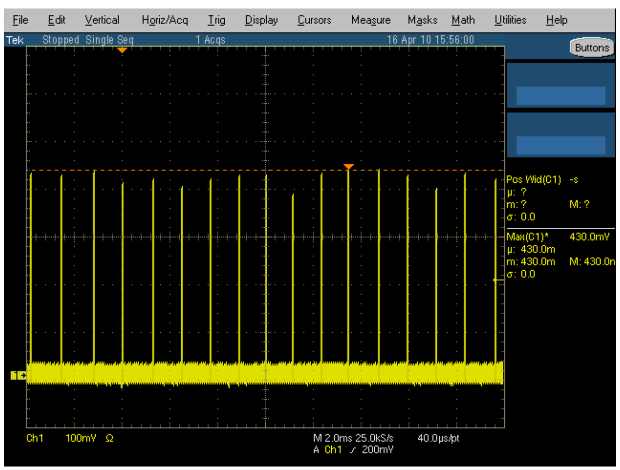


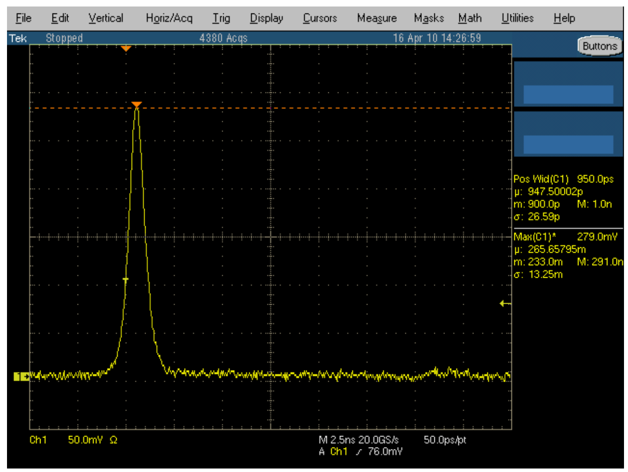
Energy: 107 μJ

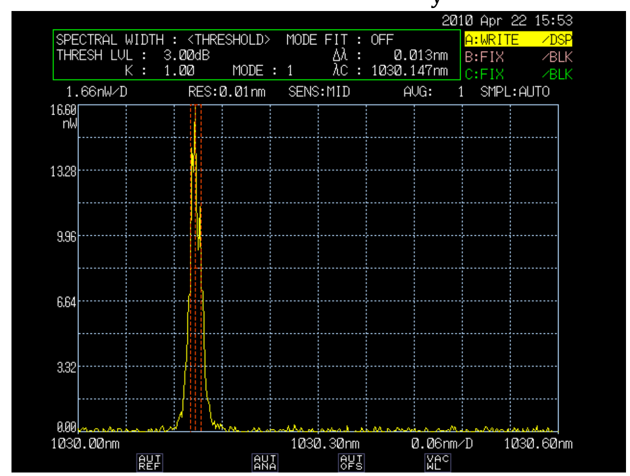
Energy variation is ~0.1% (~3 hr)

Beam Quality: $M^2_x = 1.16$

$M^2_y = 1.21$







PRF: 2 kHz

Pulsewidth: 947 ± 25 ps

Wavelength: 1030.140 ± 0.002 nm

Linewidth: <16 pm

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MOPA Laser Transmitter for IIP

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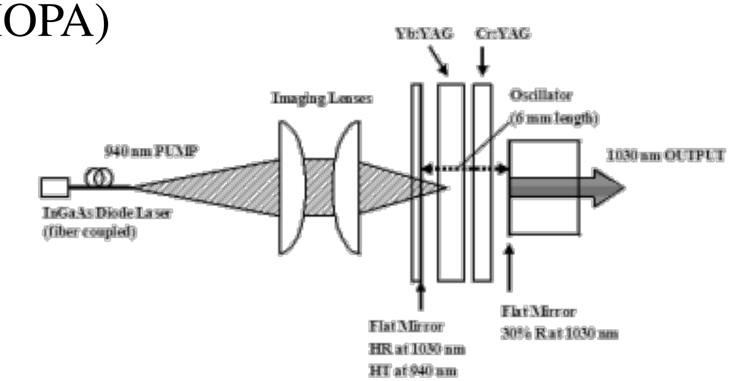
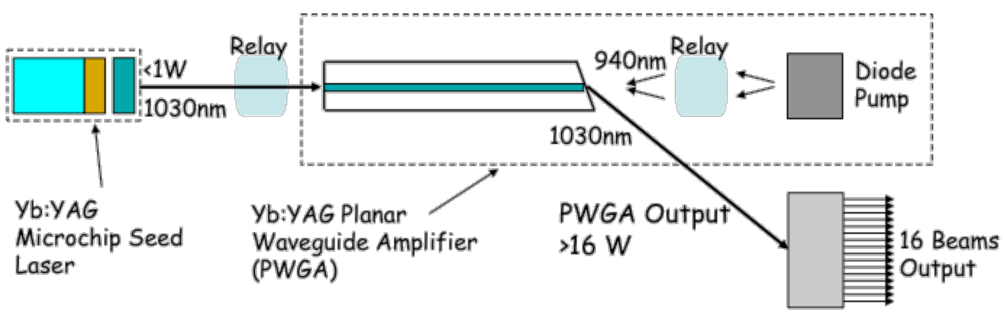
Laser Architecture: Master Oscillator Power Amplifier (MOPA)

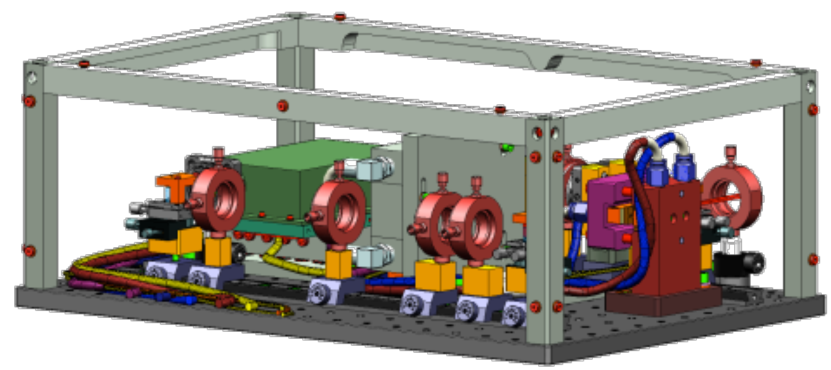
- Master Oscillator (MO): Microchip lasers (Raytheon)
  - Yb:YAG gain medium - 1030 nm
  - ~1 ns FWHM, ~100 μJ, 2-10 kHz

    ✓capable of meeting the airborne requirements of 16 beams, 5 μJ/beam with Intevac IPD
- Power Amplifier (PA): Planar waveguide amplifier (Raytheon)
  - Goal of 1.6 mJ @ 10 kHz



Master Oscillator - Microchip Laser





Raytheon

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1030 nm Photon Sensitive Detectors

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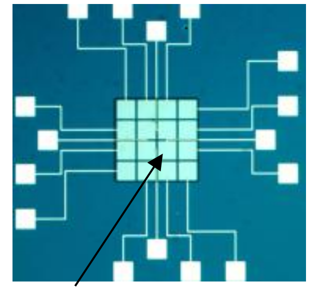
Candidate Detector Arrays –

1. Intevac Multi-anode Intensified Photodiode (IPD)

   - InGaAsP photocathode – GaAs APD anode
   - 10-20% QE, single photon sensitivity, 1 nsec analog response

INTEVAC VISION SYSTEMS

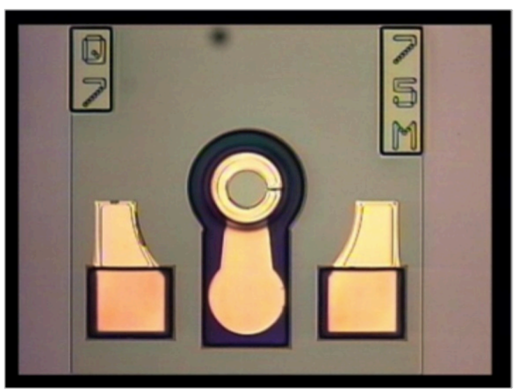


APD anode array

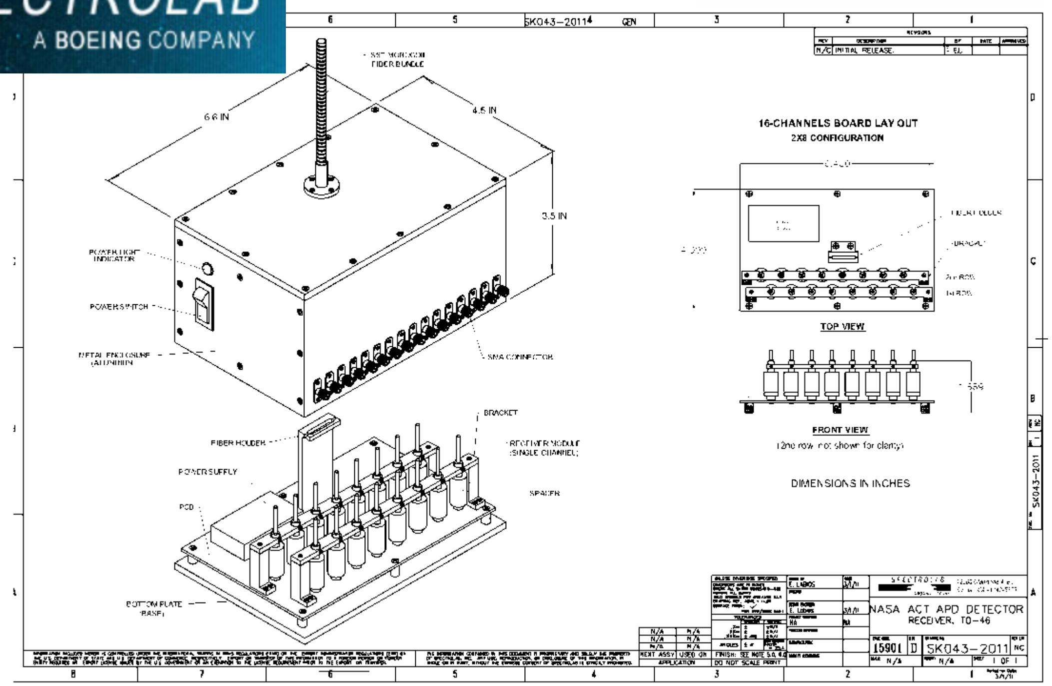
2. Spectrolab InAlAsP APD detectors (ESTO ACT-Krainak/PI)

   SPECTROLAB A BOEING COMPANY

   - 16 individual fiber coupled APDs
   - >75% QE @ 1 µm



75 micron diameter avalanche photodiode



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IPD vs InGaAs APD
GHz photoreceiver comparison

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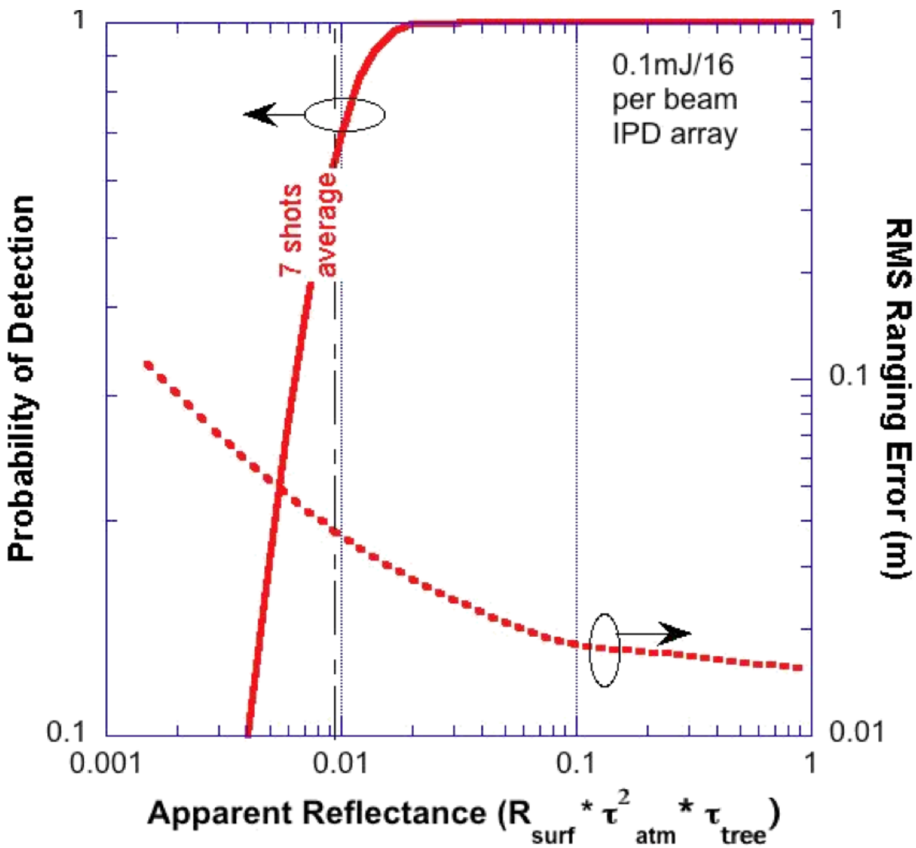
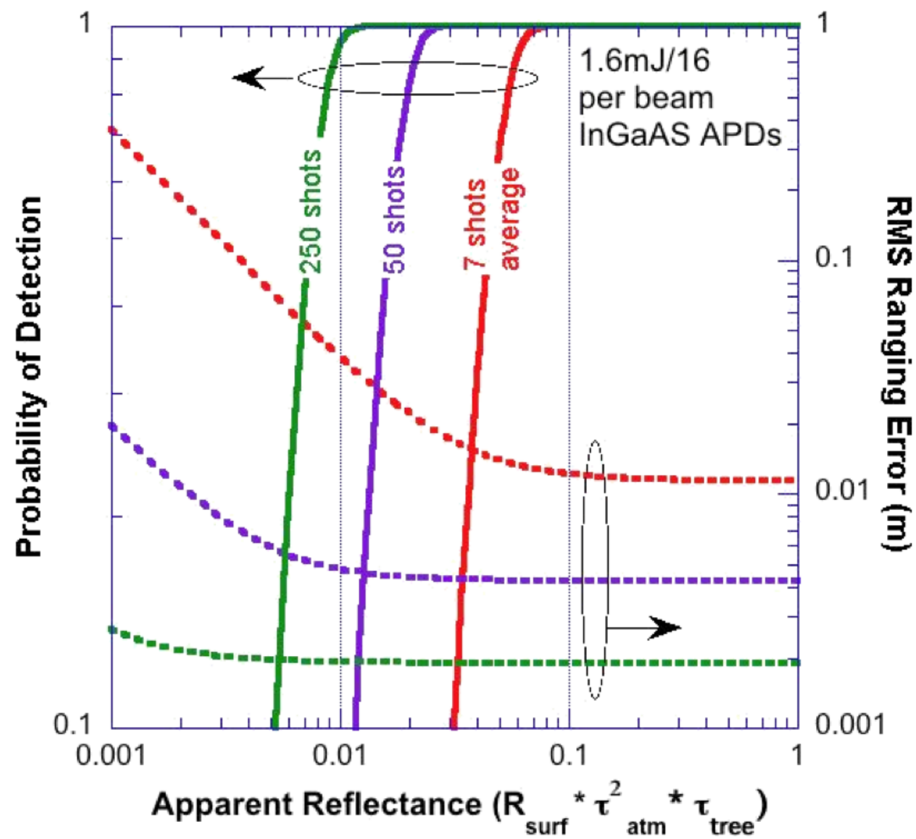
ALISTS Swath Mapper Performance with IPD receiver.



ALIST Swath Mapper Performance with I2E APD receiver.



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AIRBORNE LIST SIMULATOR (A-LISTS) DEVELOPMENT

A-LISTS Layout

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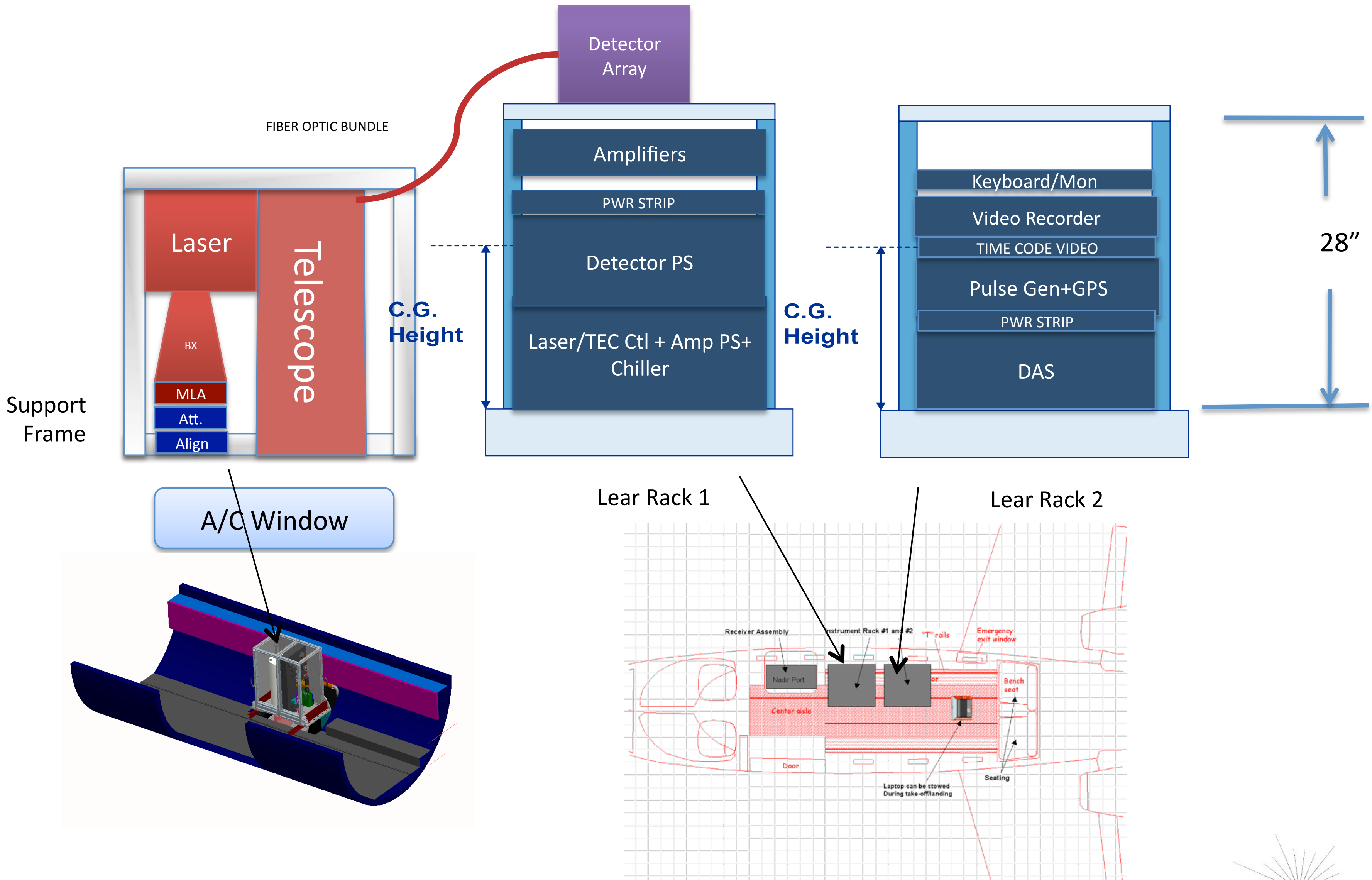

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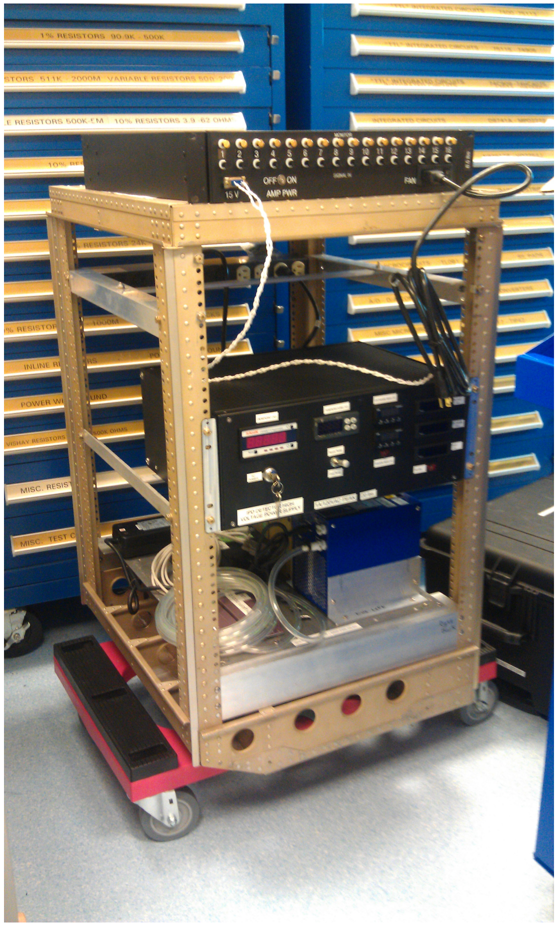
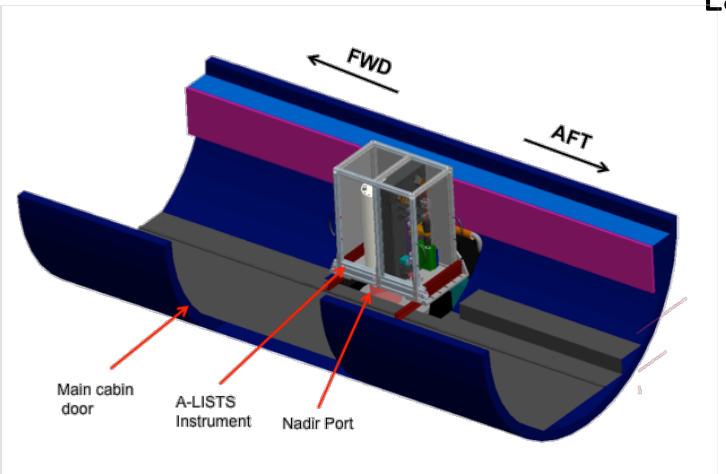
Airborne Instrument Status



Rack 1

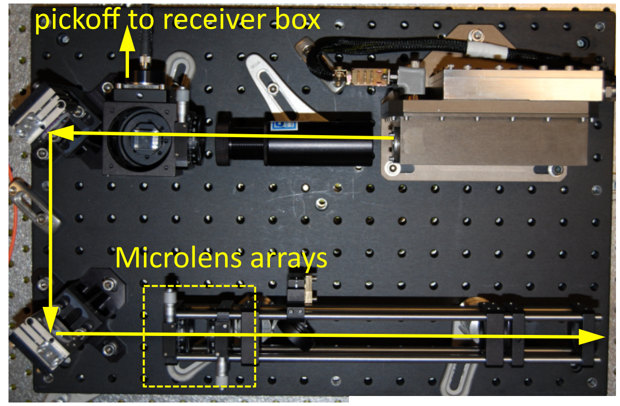
Rack 2

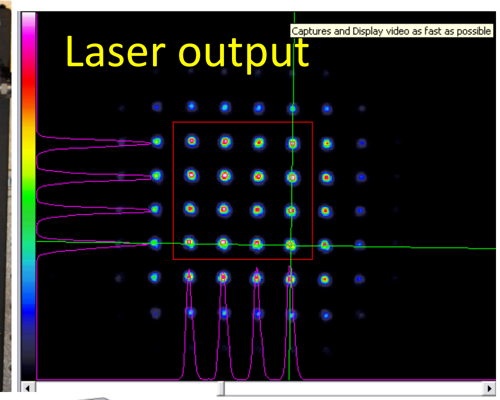
A-LISTS Transceiver



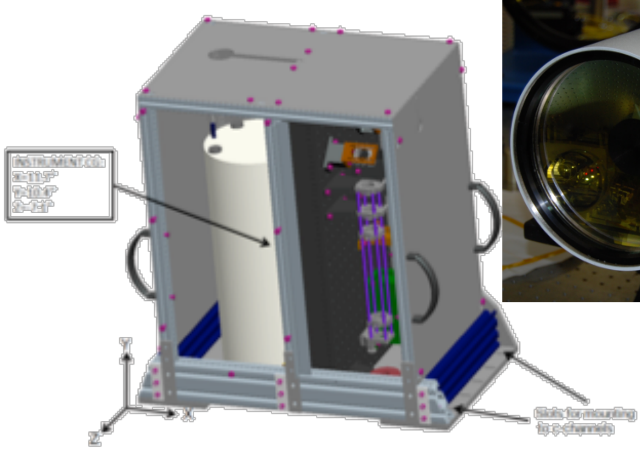
Laser Transmitter - *[using pair of microlens arrays to generate a 4x4 pattern (patent pending)]*

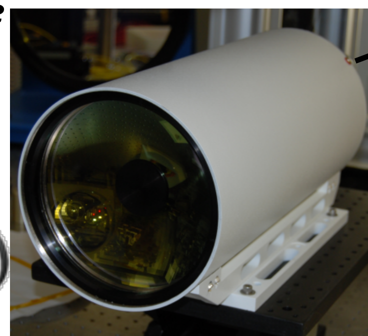
Fiber start pulse

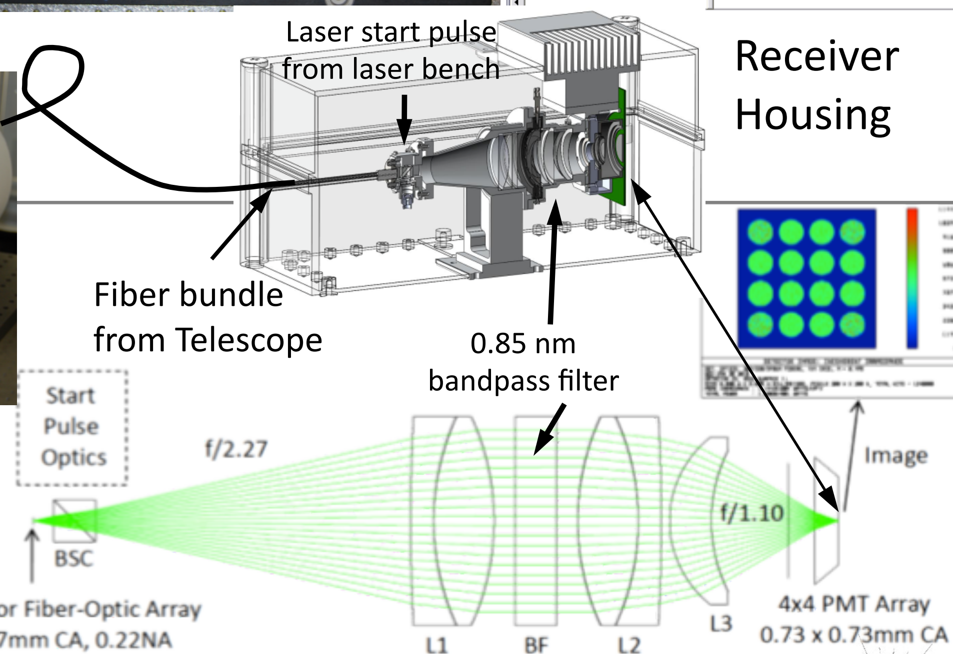




A-LISTS Transceiver Enclosure







IIP Airborne Footprint

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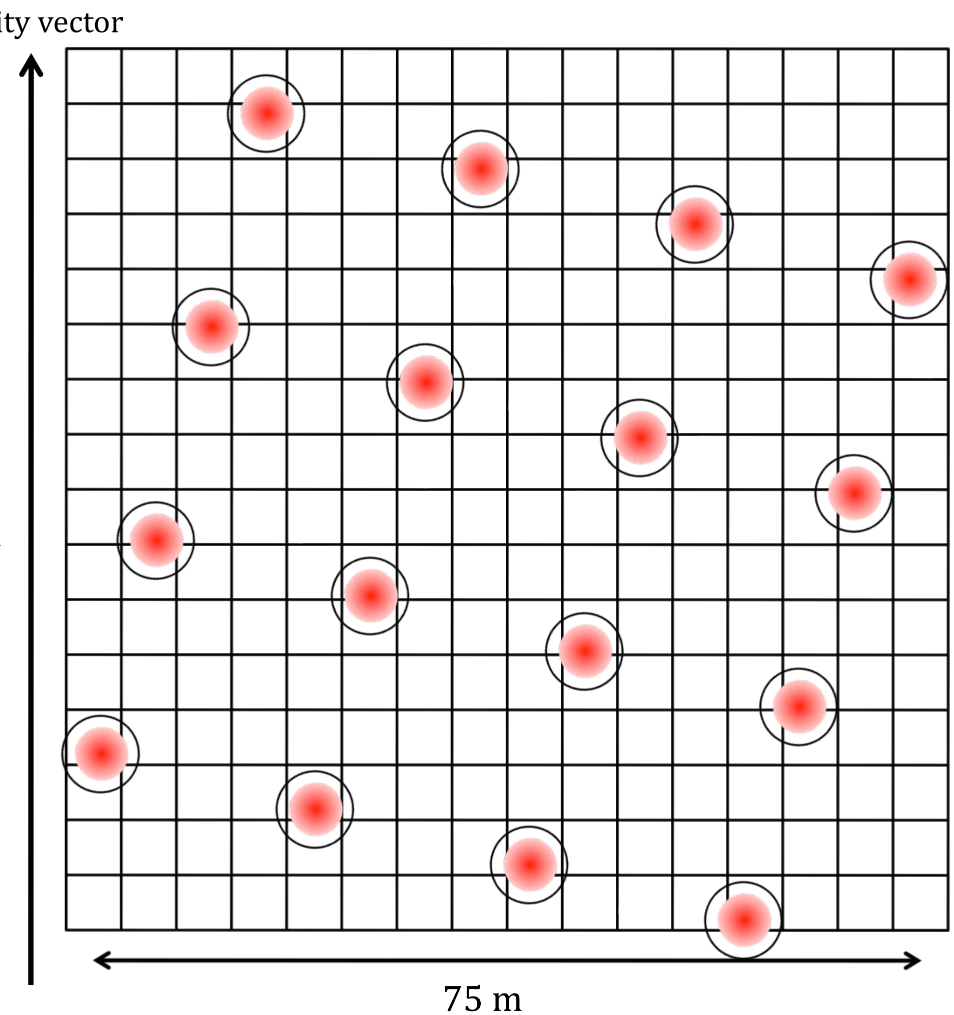

Yaw rotation of 14.5° yields uniformly spaced spots with 5 m horizontal spacing

Geolocation accuracy of 1 m to assign return to correct 5 m pixel on ground

Altitude = 10 km:
Detector FOV = 7 m (0.7 mrad)
Laser Spot = 5 m (0.5 mrad)
Laser Spot Spacing = 20 m (2 mrad)

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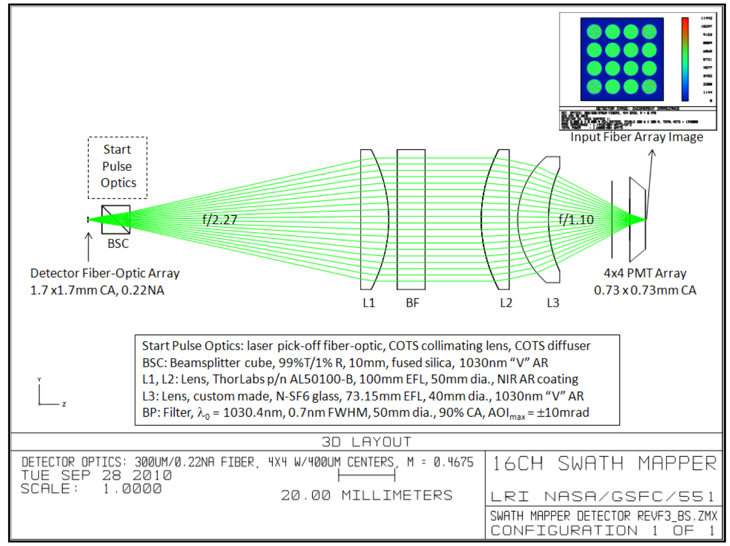
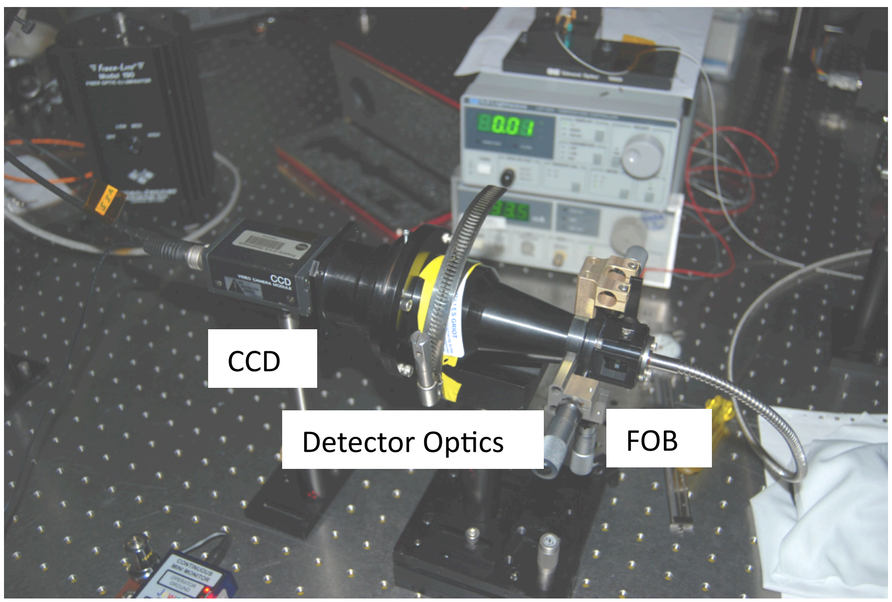
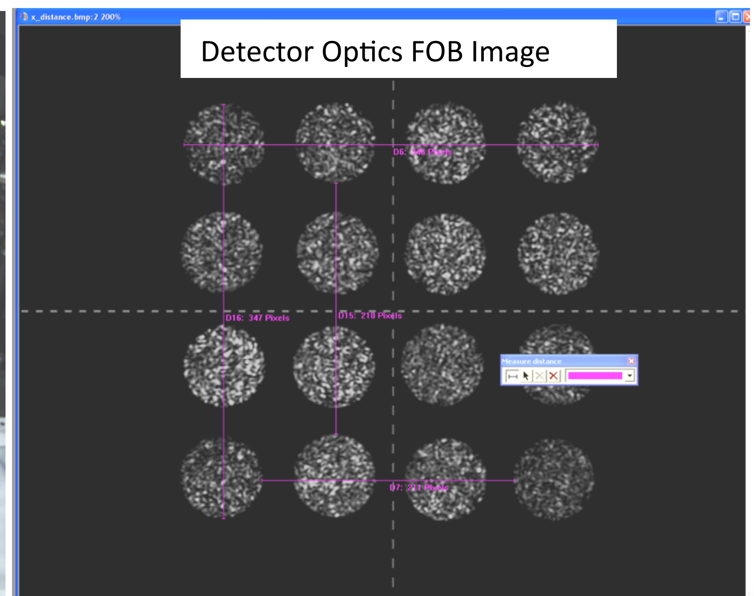
Detector Optics

- Detector Optics were designed to work with Intevac InGaAsP IPD 4x4 detector array
  - Optics have been integrated and tested with COTS bandpass filter (custom Barr filter just received)
  - Image quality and magnification meet performance requirements
  - Still need to test start pulse optics







Optical Transceiver for Ground Testing

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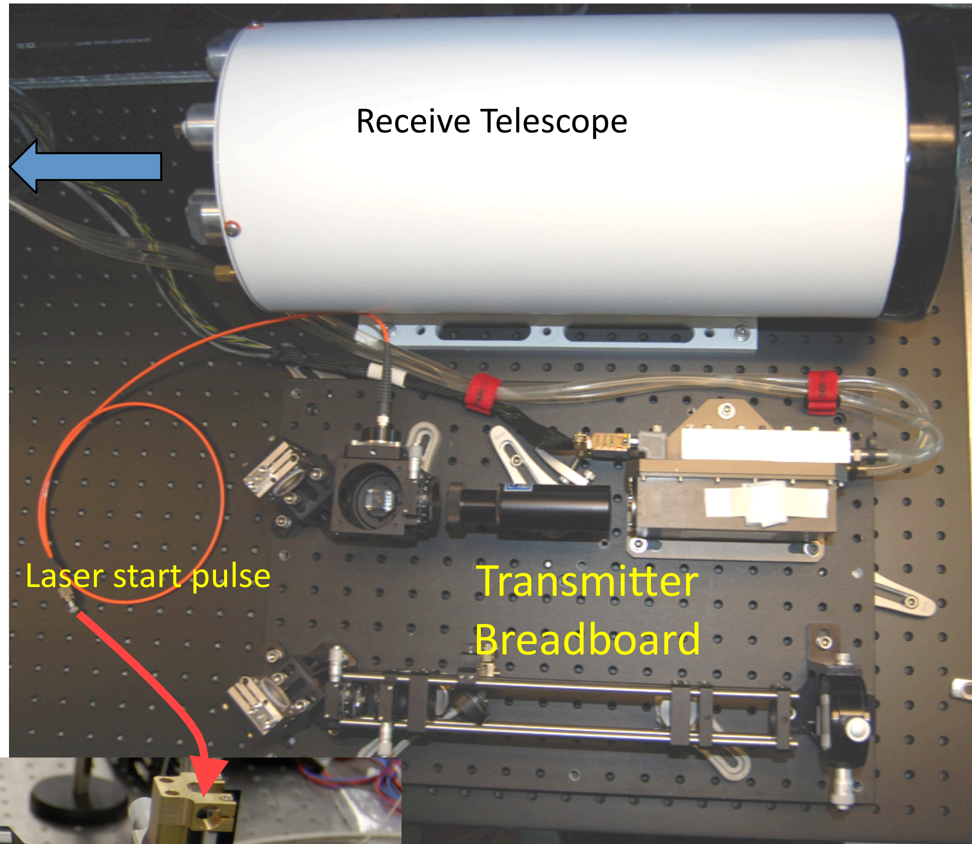
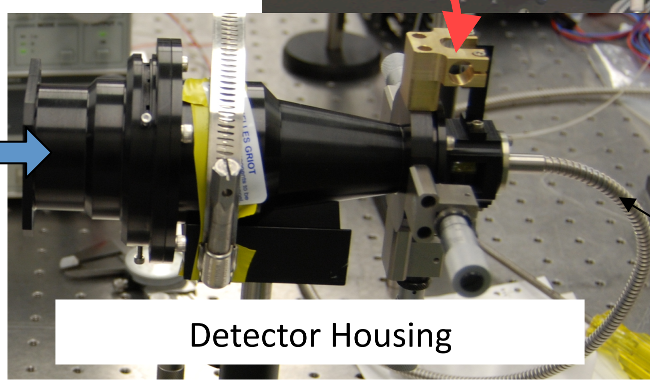
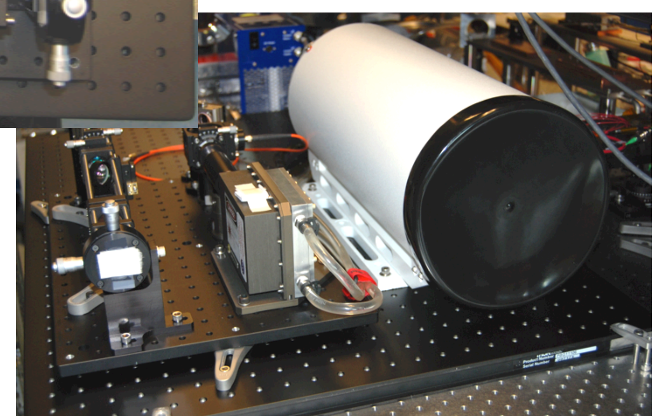
Fiber bundle to detector housing



Detector



Fiber bundle from telescope



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Ground Testing Candidate Targets for A-LISTS

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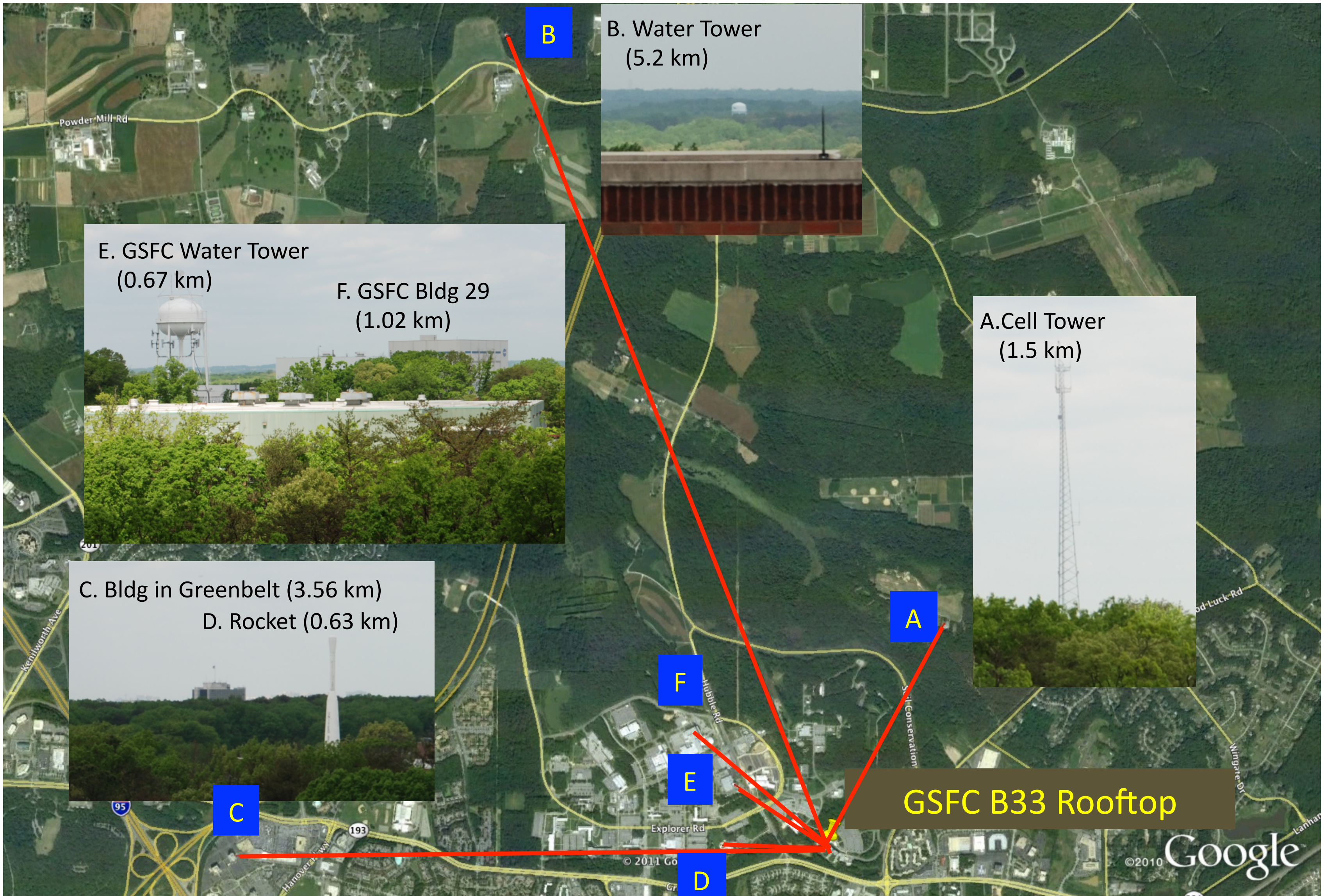

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SINGLE CHANNEL TEST RESULTS

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Single Channel Ranging Demonstration - Test Setup

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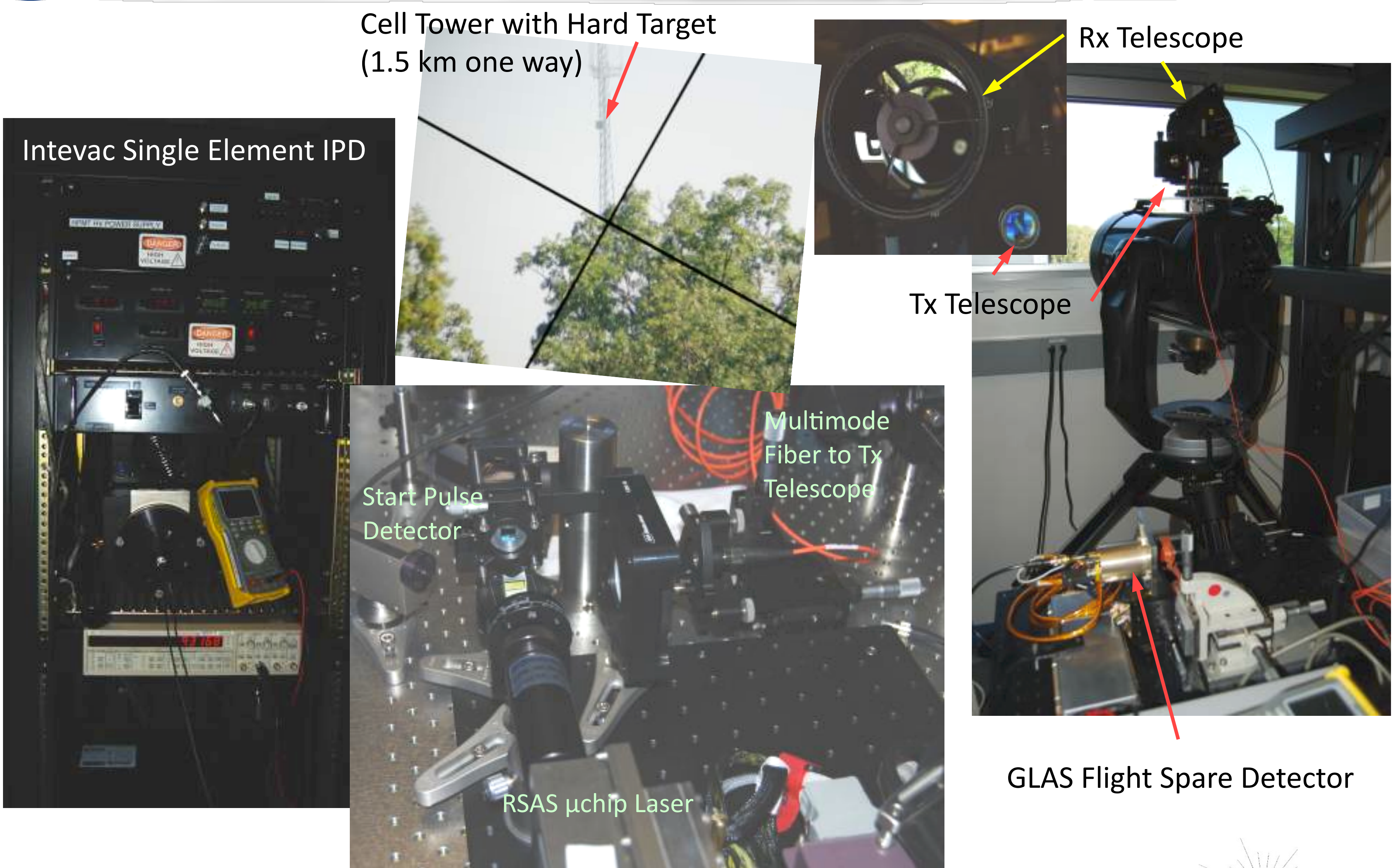

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Tower Target Board Returns

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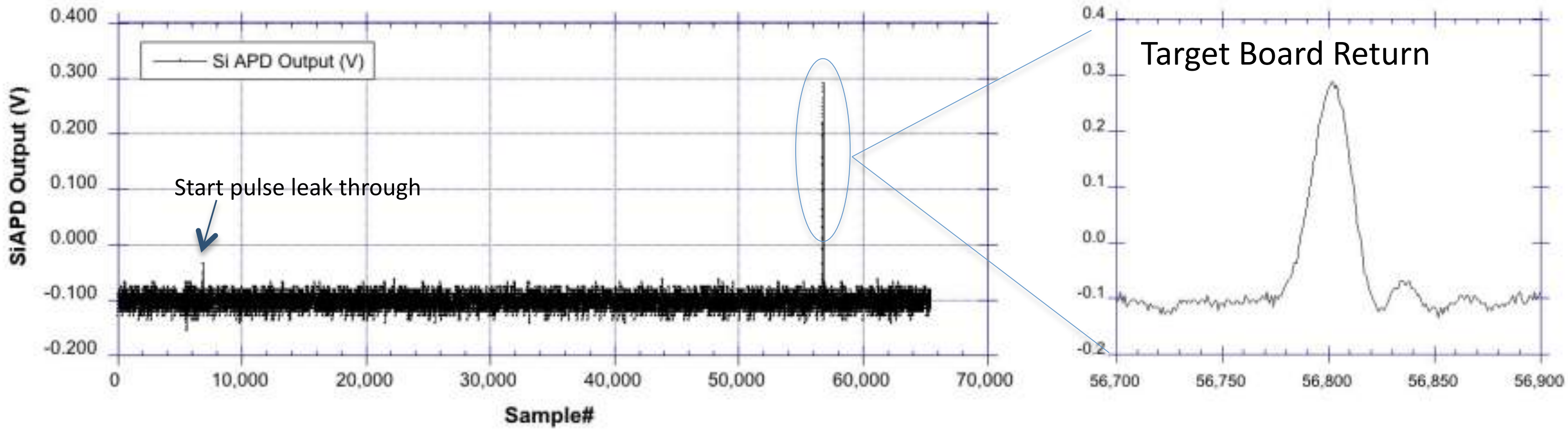
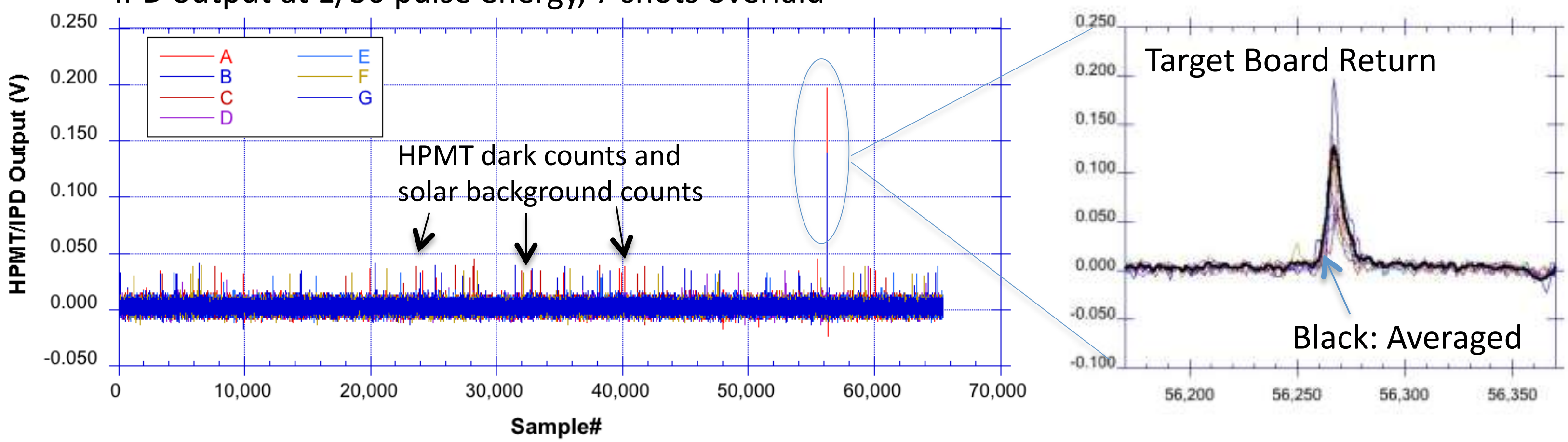
Si APD output, single shot



IPD output at 1/30 pulse energy, 7 shots overlaid



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Tower Target Board Return (Si APD & IPD)

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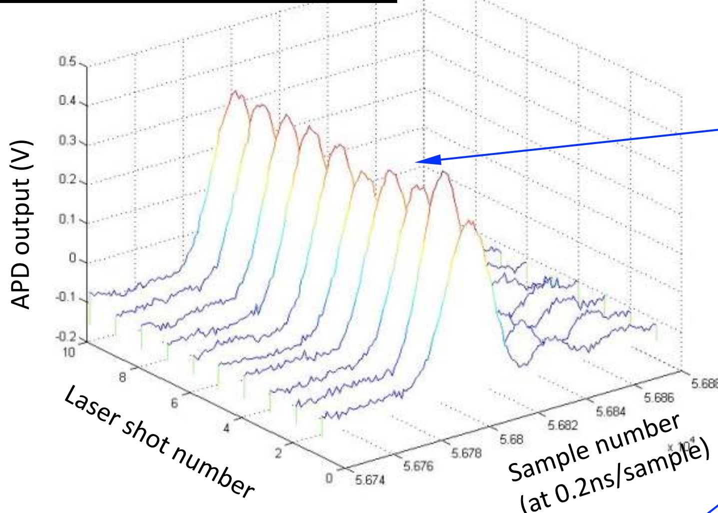
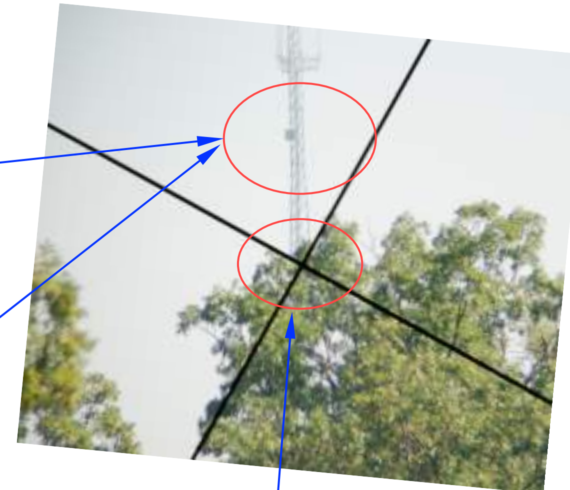
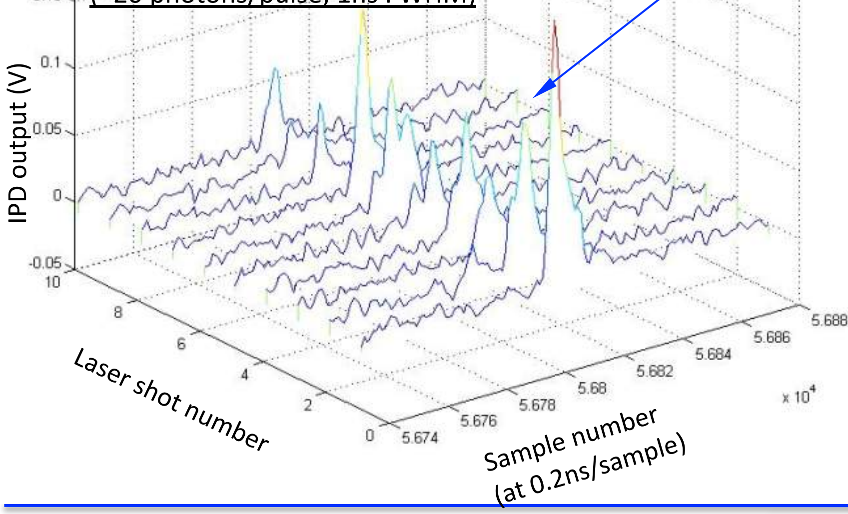
Si APD output pulse waveforms from the target board
(~700 photons/pulse, 4ns FWHM)

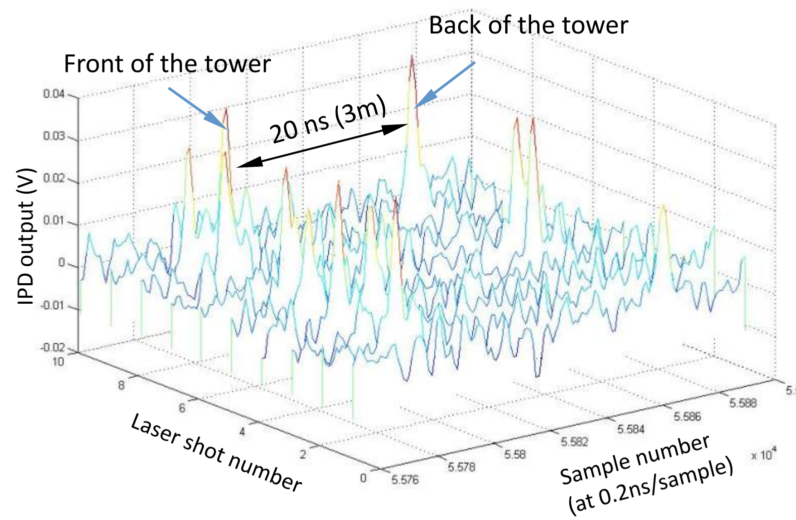




IPD output pulse waveforms from the target board
(~20 photons/pulse, 1ns FWHM)



IPD output pulse waveforms from the steel tower structure



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2011 Target Sites for Flight Demonstration

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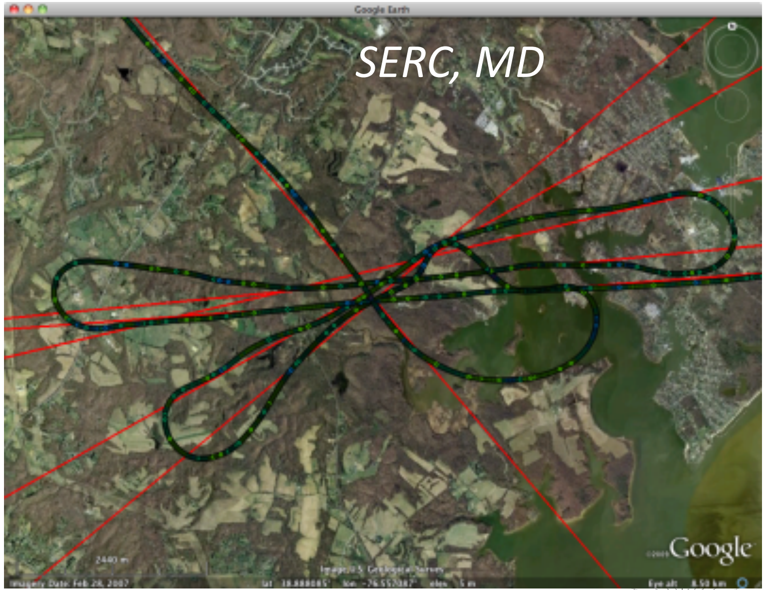
- *Closed deciduous canopy, undulating topography*
  - Smithsonian Environmental Research Center (SERC), Edgewater, MD (ICESat-2 study site)
    - Very well characterized canopy structure from ground measurements
    - Prior data collections: LVIS, Sigma Micropulse, Commercial, SIMPL, Ball ESFL
- *Closed deciduous canopy, rugged topography*
  - Liberty Reservoir, Baltimore County, MD
    - Prior data collections: LVIS, Commercial
- *Open coniferous canopy, flat topography*
  - Pine Barrens, NJ (ICESat-2 study site)
    - Prior data collections: Sigma Micropulse, Commercial, SIMPL
- *Diverse, managed coniferous canopy, flat topography*
  - Huron National Forest, MI
    - Prior data collections: SIMPL
- *Non-vegetated, rough topography*
  - Boulder Field, Hickory Run State Park, MD
    - Prior data collections: SLICER, Commercial
- *Bare to sparse vegetation, flat topography*
  - Assateague Island National Seashore, MD
    - Prior data collections: ATM
- *Urban*
  - Ocean City, MD
    - Prior data collections: ATM



Summary

- Develop key technologies and an airborne instrument to meet the LIST mission requirements and provide scalability study for spaceborne mission.
    a. High efficiency, short pulse (< 1 ns) multi-beam laser transmitters;
    b. Higher sensitivity array detectors, waveform capturing;
    c. Similar spatial resolution (spot diameters) as LIST;
    d. to collect LIST like signal to study data reduction technique.
- Advanced TRL of critical subsystems (Laser & Detector) on airborne platform.
- Will demonstrate LIST-type measurements over a variety of surface types, including those of vegetation canopy and substructures.
- Data system – requires multi-channel, high sampling rate and bandwidth digitizers with minimum of 8-bit resolution and high data transfer rate.
- First flight – September 2011

Acknowledgement

Goddard Space Flight Center

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for their technical support

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